



# CLARREO

## **CLARREO Reflected Solar Spectrometer: Reference Inter-Calibration**

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# CLARREO

## Presentation Outline

- 1) **Brief overview CLARREO RS Reference Inter-calibration (RI) status at MCR:**
  - Mission configuration in RS;
  - Reference Inter-Calibration goals;
  - CLARREO RS RI Level-2 mission requirements.
- 2) **Uncertainty Estimates for Imager Reference Inter-calibration with CLARREO RSS.**
- 3) **CLARREO RS Reference Inter-calibration future work:**
  - Baseline CLARREO RS activities;
  - ROSES 2011 proposals;
  - Planned publications.
- 4) **Announcement: new SCIAMACHY Level-1 Spectral Data at NASA LaRC**

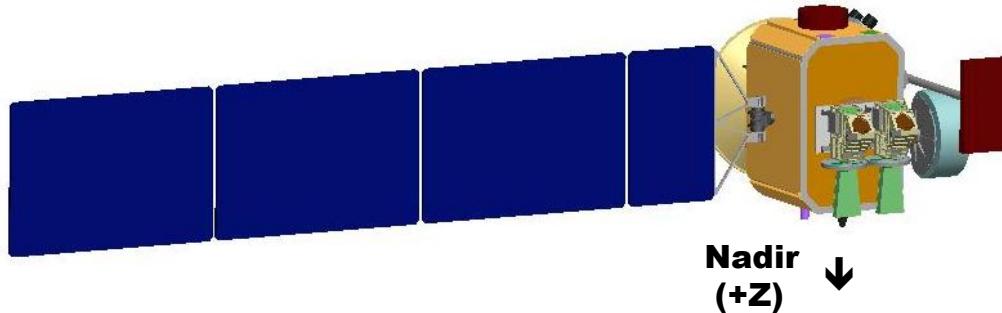
# 1) Overview CLARREO RS Reference Inter-calibration Status at MCR:

## 1. CLARREO RS Configuration (*CLARREO Engineering Team*)

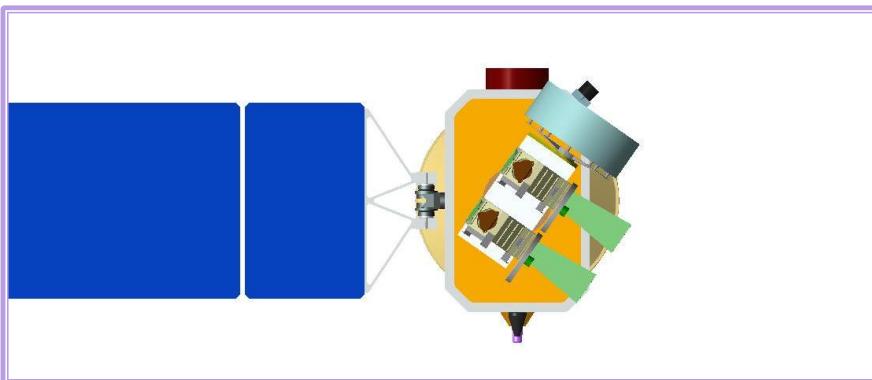
**2D pointing ability is required to match observations in VZA and RAZ.**

**Single axis gimbal provides for “Roll” or cross-track pointing**

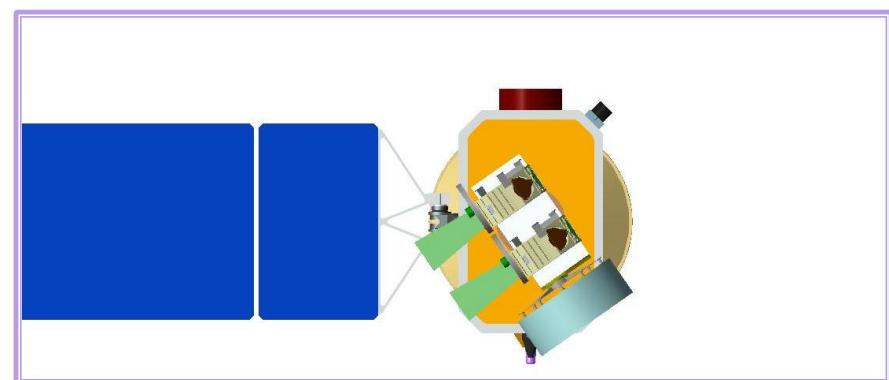
**Roll angle range: +/- 55° is required**



**MCR concept requires “yaw” or +Z rotation by the S/C bus.  
Yaw angle range: +/- 84°**



**OFF Nadir +55°**



**OFF Nadir -55°**

# 1) Overview CLARREO RS Reference Inter-calibration Status at MCR:

## 2. CLARREO RSS Inter-Calibration Goals

- ◆ MCR: Goals are set at RI noise level  $\approx 1\%$  (sources: instrument + data matching)
- ◆ RI error contribution  $\leq 0.3\%$  ( $k=2$ ) over auto-correlation time period = 18 months

### 1) CLARREO Inter-Calibration Goals: CERES

Parameter	Time scale	Variable	RI Error, k=2 (%)
Offset	monthly	All Data	$\leq 1.2$
Gain	monthly	All Data	$\leq 1.2$
SRF Degradation	semi-annually	Scene Type (clro)	$\leq 0.7$
Non-Linearity	Validation Annually, RI Error 0.3%( $k=2$ )		
Sensitivity to Polarization	Not Sensitive, Validation Annually, RI Error 0.3%( $k=2$ )		

### 2) CLARREO Inter-Calibration Goals: VIIRS

Parameter	Time scale	Variable	RI Error, k=2 (%)
Baseline Offset	monthly	VZA(7), DOP, HAM	$\leq 1.2$
Baseline Gain	monthly	VZA(7), DOP, HAM	$\leq 1.2$
Sensitivity to Polarization	semi-annually	VZA(7), DOP, $\chi$ (9), HAM	$\leq 0.7$
SRF CW Shift	Validation Annually, RI Error 0.3 %( $k=2$ )		
Non-Linearity	Validation Annually, RI Error 0.3%( $k=2$ )		

# **1) Overview CLARREO RS Reference Inter-calibration Status at MCR:**

## **3. CLARREO RS RI Level-2 Science Requirements (based on pre-MCR studies):**

- CLARREO RSS accuracy over mission lifetime 0.3% (k=2).**
- Uncertainty contribution from RI 0.3% (k=2) over 18 months time period.**
- 2D pointing ability to provide matching in both VZA and RAZ.**
- Geolocation uncertainty of CLARREO RS GFOV in Level-1 data  $\leq$  100 m (TBD).**
- Data matching within +/- 5 min, +/- 1° in SZA, VZA and RAZ, spatial averaging over at least 10 km  $\times$  10 km area (nadir) to limit matching noise to 1% (k=1).**
- Spatial GFOV size: 70% of energy in 0.5  $\times$  0.5 km at nadir (90% in 1  $\times$  1 km).**
- Preferred Orbit: 90° Polar orbit, 609 km altitude,  $\Omega = 0^\circ$  or  $180^\circ$ .**
- Spatial coverage: CLARREO RSS swath = 100 km.**
- Spectral range: from 320 nm to 2300 nm wavelength (CERES intercal).**
- Spectral sampling: every 4 nm (VIIRS intercal).**
- Polarization Distribution Models to address sensor sensitivity to polarization.**



## **2) Uncertainty Estimates for Imager Reference Inter-calibration with CLARREO RSS**

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**1 - NASA LaRC, Hampton, VA**

**2 - SSAI, Hampton, VA**

**3 – NASA GSFC, Greenbelt, MD**

**(summary from paper draft)**

# **CLARREO RS RI: Polarization Parameters**

**Imaging radiometers (MODIS, VIIRS) are sensitive to polarization  
Polarization information on orbit from modeling**

**Degree of linear polarization at TOA ( $P$  or DOP):**

$$P = \frac{L_p}{L} = \frac{\sqrt{Q^2 + U^2}}{L} = \frac{\rho_p}{\rho} .$$

**Polarization angle defined relative to viewing plane  
(PARASOL definition, range from -45° to 135°):**

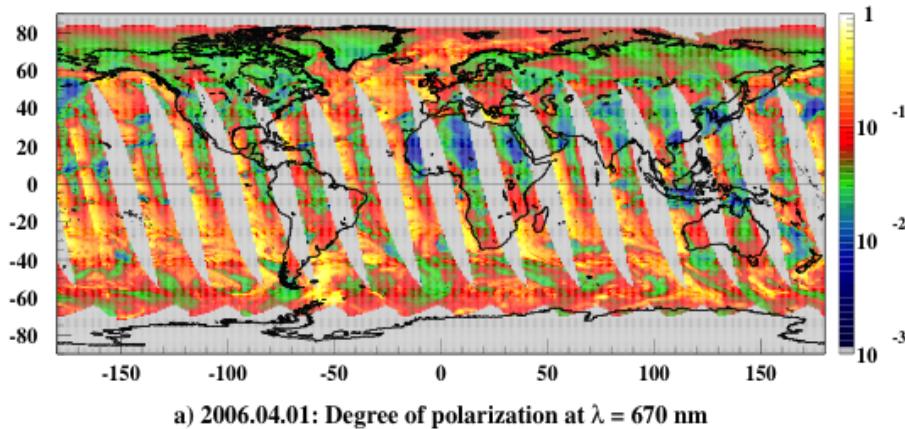
$$\chi = \begin{cases} \tan^{-1}(U/Q)/2 \\ \tan^{-1}(U/Q)/2 + \pi/2 & \text{if } Q < 0. \end{cases}$$

**Notes:**

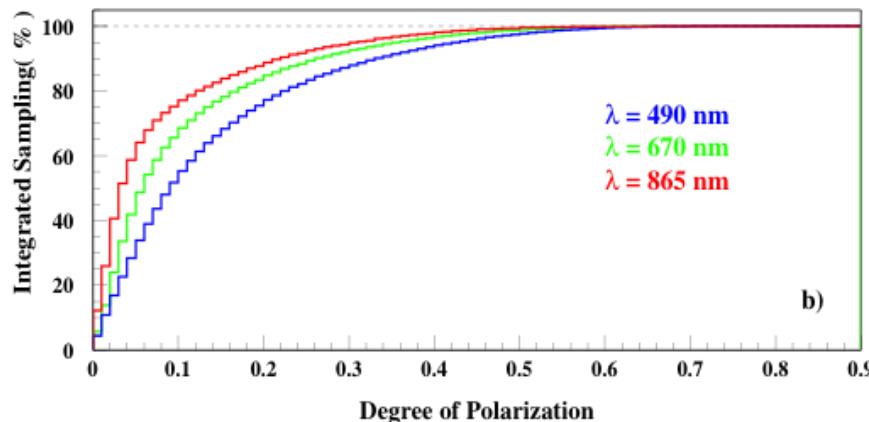
- $U$  is defined relative to radial direction in viewing plane
- The  $\chi$  should be 90° for scattering in principle plane

# Polarization Data from PARASOL (2006.04.01)

Used for Empirical Polarization Distribution Models



a) 2006.04.01: Degree of polarization at  $\lambda = 670$  nm



**PARASOL data:**  
**Simulated cross-track sampling,**  
 **$1^\circ \times 1^\circ$  lon/lat grid,**  
 **$\lambda = 670$  nm.**

**Integral sampling for 3 PARASOL  
Polarization bands**

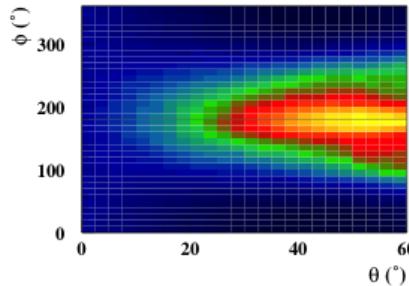
**Note:** Average DOP level is from  
0.1 – 0.3 depending on  $\lambda$ .

# Examples of Empirical PDMs (12 days of PARASOL data)

Wavelength = 670 nm,  $40^\circ < \text{SZA} < 50^\circ$

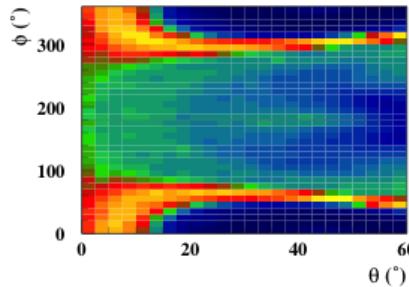
DOP:

a) CLR Ocean: P and  $\chi$

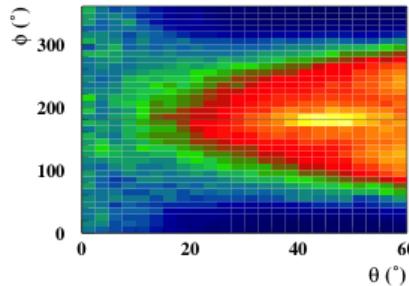


Polarization angle:

b) OVC Water Clouds: P and  $\chi$



c) OVC Ice Clouds: P and  $\chi$



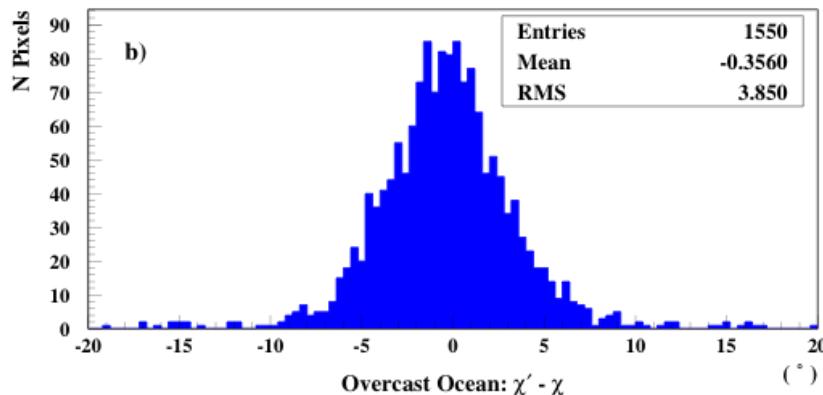
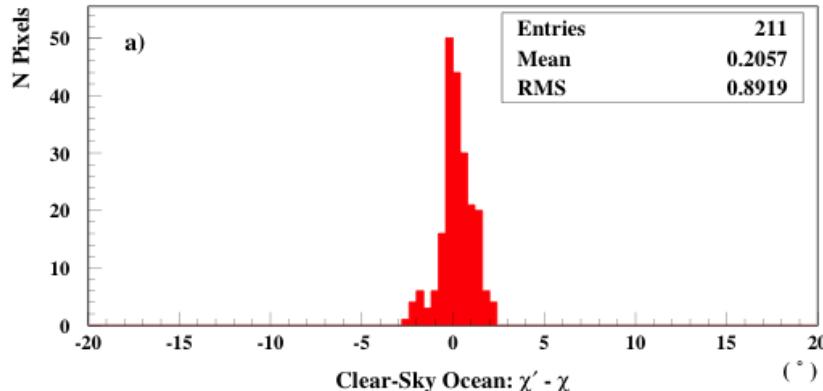
a) Clear-sky ocean:  
WS < 2.5 m/s

b) Overcast water clouds over ocean:  
5 < OD < 10

c) Overcast ice clouds over ocean:  
5 < OD < 10

**Note:** DOP patterns are strongly dependant on scene type, but the Polarization angle is very similar.

# Difference between Measured Polarization angle and Assumed (90° relative to scattering plane)



**Typical geometry bin:**

**$30^\circ < \text{SZA} < 40^\circ$**

**$20^\circ < \text{VZA} < 25^\circ$**

**$200^\circ < \text{RAZ} < 220^\circ$**

**Note: RMS includes PARASOL observation uncertainty.**

**Note: Taking into account imager characterization before launch,  $15^\circ - 20^\circ$  angular interval: The PDMs for polarization angle might not be required.**

**Theoretical PDMs:** See Wenbo Sun's presentation on theoretical modeling of polarization at TOA. The goal is to expand the empirical PDMs over VIS and Near-IR spectral range for all scene types.

# Imager Calibration Model (MODIS as reference)

How we access inter-calibration parameters

**MODIS calibration model, reflectance factor (*Xiong et al., 2003, 2006*)**

$$\rho_{EV} \cos(\theta_{EV}) = m_1 d n_{EV} d_{ES}^2 (1 + k_{inst} \Delta T) / R V S_{EV}$$

$\theta_{EV}$  - solar zenith angle

$m_1$  - factor from solar calibration (SD and SD Monitor)

$d n_{EV}$  - detector response to earth radiance

$d_{ES}$  - sun-to-earth distance

$k_{inst}$  - temperature correction coefficient

$\Delta T$  - temperature difference from reference value

$R V S_{EV}$  - response versus scan angle

**Simplified RI Imager calibration model with polarization factor in:**

$$\rho^{sensor} = (1 + mP) \rho_0$$

$m$  is sensitivity to polarization, it is function of  $\theta$  and  $\chi$

$P_0$  is  $\rho_{EV}$

**Follows VIIRS memo *Wang 2003*, similar to *Sun and Xiong 2007***

# CLARREO/Imager RS RI Constraints

**Constraints for CLARREO/Imager RI samples on orbit:**

$$\begin{cases} \rho^{clarreo} = \rho_0 & \text{if } P = 0. \\ \rho^{clarreo} = (1 + mP) \rho_0 & \text{if } P > 0. \end{cases}$$

**CLARREO/Imager reflectance difference (scalar and linear terms):**

$$\begin{cases} \rho_0 - \rho^{clarreo} = A_0 + G_0 \rho^{clarreo} & \text{if } P = 0. \\ \rho^{sensor} - \rho^{clarreo} = A_p + G_p \rho^{clarreo} & \text{if } P > 0. \end{cases}$$

**$A_0$  and  $G_0$  - for samples with not polarized reflectance**

**$A_p$  and  $G_p$  - for samples with polarized reflectance**

**Let us call  $A$ 's and  $G$ 's reference inter-calibration offset and gain...**

## CLARREO RS RI: Imager Sensitivity to Polarization

$$G_p - G_0 = mP$$

**RI gain difference for non-polarized and polarized reflectance is attributed to sensitivity to polarization**

$$m = \frac{(G_p - G_0)}{P} = \frac{\Delta G}{P}$$

**Imager sensitivity to polarization on orbit**

$$\frac{\sigma_m}{m} = \sqrt{\left(\frac{\sigma_{\Delta g}}{\Delta G}\right)^2 + \left(\frac{\sigma_p}{P}\right)^2}$$

**Relative uncertainty of sensitivity to polarization on orbit**

$$\frac{\sigma_{\Delta g}}{\Delta G} = \sqrt{\frac{\sigma_{g_0}^2 + \sigma_{g_p}^2}{\Delta G}}$$

- First term is relative uncertainty of RI gain difference (RI sampling).
- Second term is relative uncertainty of the PDMs.

# CLARREO/Imager RI: Resulting Radiometric Uncertainty

For fixed  $\theta$  and  $\chi$  values, assuming no correlation, reflectance variance:

$$(\sigma^{sensor})^2 = (1 + mP)^2 \sigma_0^2 + (m\rho_0)^2 \sigma_p^2 + (P\rho_0)^2 \sigma_m^2$$

Then, relative radiometric uncertainty:

$$\frac{\sigma^{sensor}}{\rho^{sensor}} = \sqrt{\left(\frac{\sigma_0}{\rho_0}\right)^2 + \frac{P^2 \sigma_m^2 + m^2 \sigma_p^2}{(1 + mP)^2}}$$

First term is uncertainty for non polarized reflectance.  
Second term is from polarization effects.

$$\frac{\sigma_0}{\rho_0} = \sqrt{\left(\frac{\sigma^{clarreo}}{\rho_0}\right)^2 + \left(\frac{\sigma_{intercal}}{\rho_0}\right)^2 + \left(\frac{\sigma_{residue}}{\rho_0}\right)^2}$$

The first term is combined accuracy of CLARREO, RI random error, and remaining Imager uncertainty (e.g. month-to-month stability).

# Numerical Estimates: List of Calculations

Four illustrative examples for CLARREO RS inter-calibration

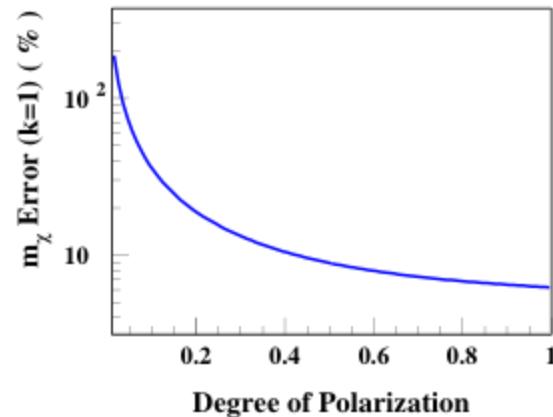
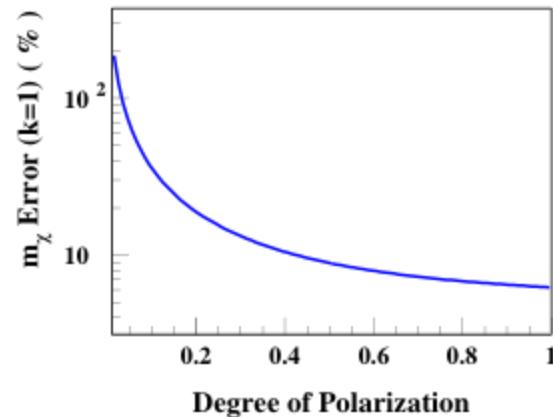
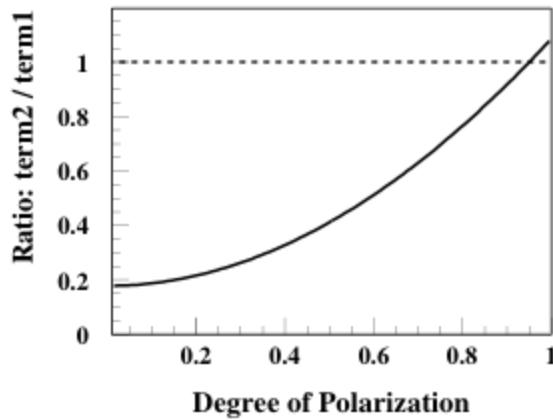
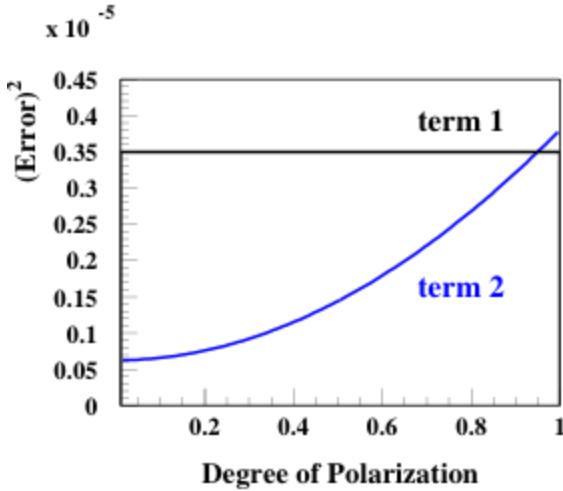
	Purpose	$m$	$\sigma_{pdm}$	$\sigma_{a0}$	$\sigma_{gp}$	$\sigma_{clarreo}$	$\sigma_{residue}$
1	RS RI Goal	3	5	0.05	0.10	0.15	0.10
2	PDM Error ( $\sigma_{pdm}$ )	3	5, 10, 15	0.10	0.15	0.15	0.10
3	Sampling Error ( $\sigma_{a0}$ )	3	5	0.05, 0.1, 0.15	0.15	0.15	0.10
4	Sensitivity to Polarization	3, 5, 10	5	0.10	0.15	0.15	0.10

**Values of input parameters used in numerical estimates. The uncertainties for inter-calibration offset and gains, CLARREO RSS accuracy and remaining RI Imager bias are relative to  $\rho_0$ .**

**All uncertainty values are given in % and for  $k = 1$ .**

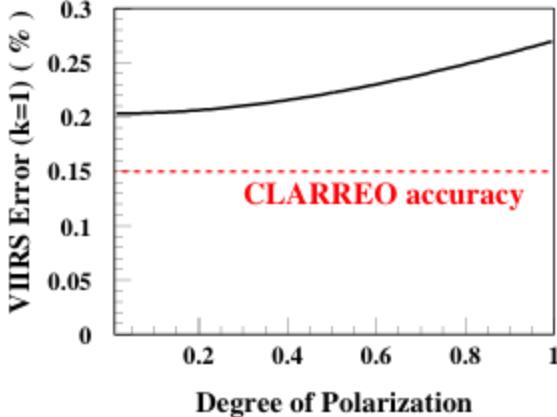
# Numerical Estimates: CLARREO RS RI Goal (best RI sampling)

Two independent measurements of  $m$  on orbit



**Inputs for calculation:**

- $m = 3\%$
- $\sigma_{pdm} = 5\%$
- $\sigma_{g0} = 0.05\%$
- $\sigma_{gp} = 0.10\%$
- $\sigma_{clarreo} = 0.15\%$
- $\sigma_{sensor} = 0.10\%$



# Numerical Estimates: PDMs Uncertainty (nominal RI sampling)

## Single measurement of $m$ on orbit

Inputs for calculation:

$m = 3\%$

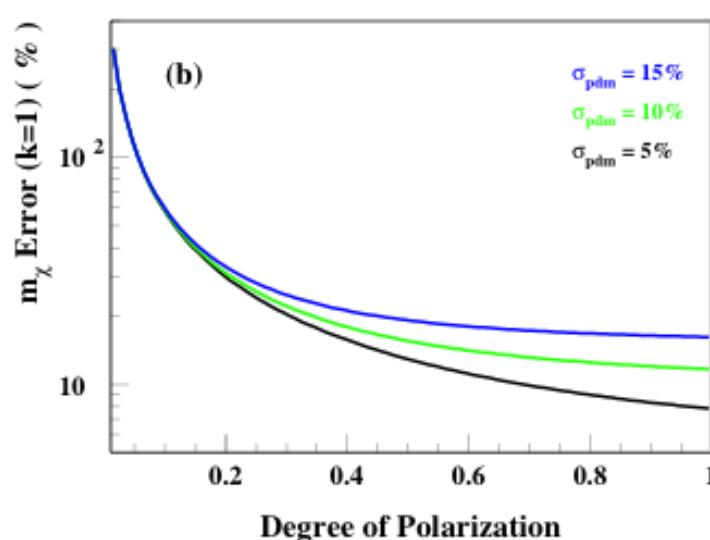
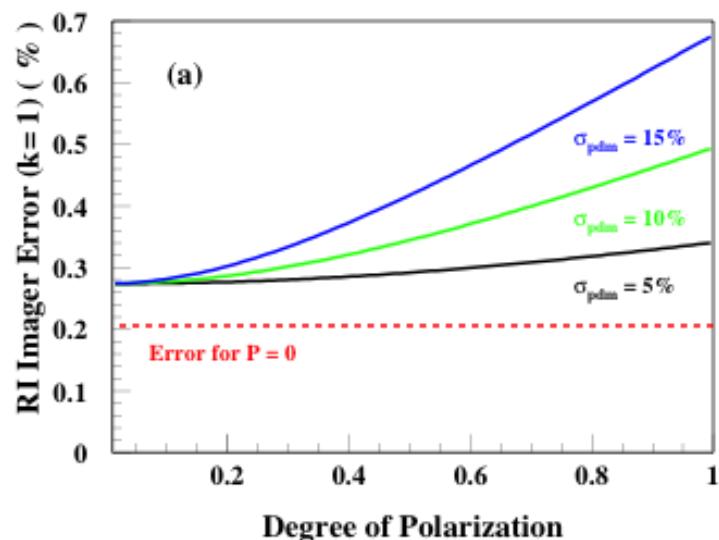
$\sigma_{\text{pdm}} = 5\%, 10\%, 15\%$

$\sigma_{g0} = 0.10\%$

$\sigma_{gp} = 0.15\%$

$\sigma_{\text{clarreo}} = 0.15\%$

$\sigma_{\text{sensor}} = 0.10\%$



# Numerical Estimates: various RI Sampling ( $A_0$ and $G_0$ )

## Single measurement of $m$ on orbit

**Inputs for calculation:**

$m = 3\%$

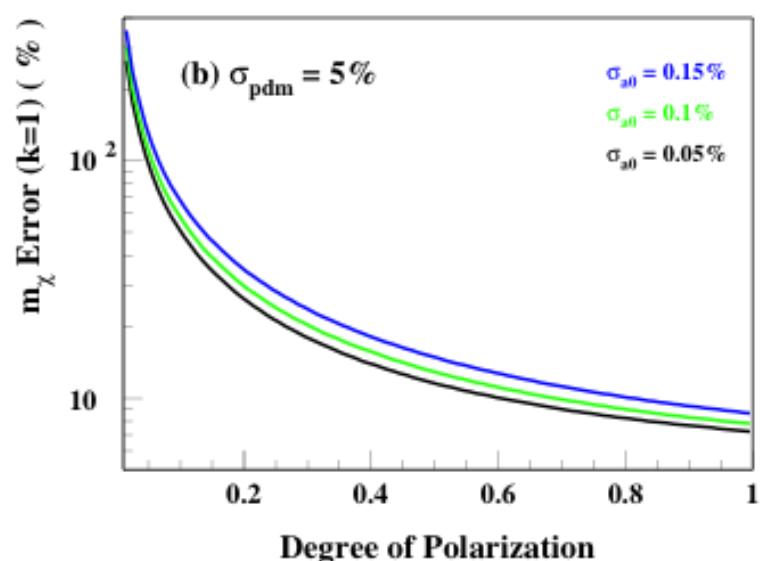
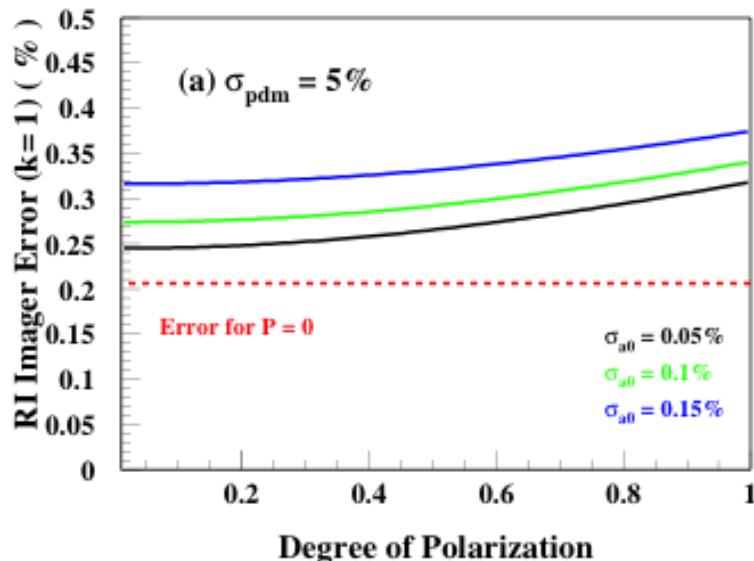
$\sigma_{\text{pdm}} = 5\%$

$\sigma_{g0} = 0.05\%, 0.10\%, 0.15\%$

$\sigma_{\text{gp}} = 0.15\%$

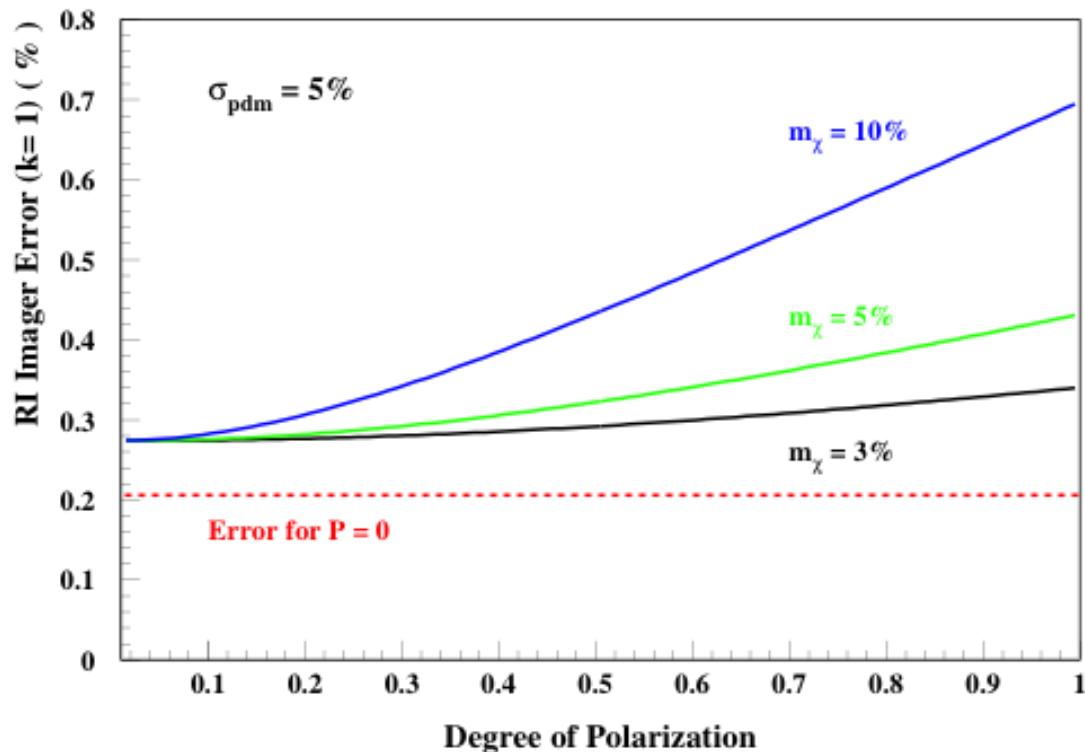
$\sigma_{\text{clarreo}} = 0.15\%$

$\sigma_{\text{sensor}} = 0.10\%$



# Numerical Estimates: Imager Sensitivity to Polarization

## Single measurement of $m$ on orbit



**Inputs for calculation:**

$m = 3\%, 5\%, 10\%$

$\sigma_{\text{pdm}} = 5\%$

$\sigma_{g0} = 0.10\%$

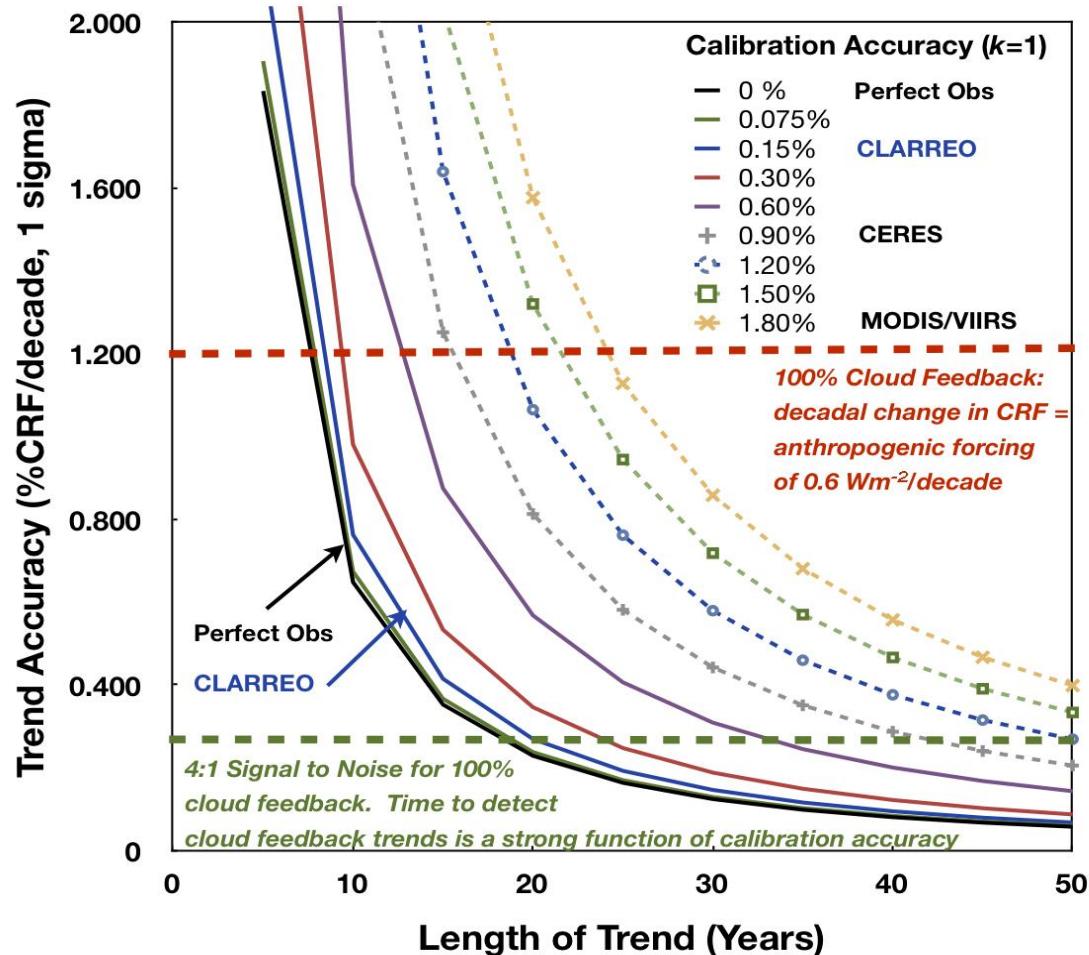
$\sigma_{gp} = 0.15\%$

$\sigma_{\text{clarreo}} = 0.15\%$

$\sigma_{\text{sensor}} = 0.10\%$

# Summary: Trend Accuracy

## Trend Accuracy & Calibration Accuracy: Reflected Solar



← Study by B.A. Wielicki

### Notes:

**On average we can expect RI Imager calibration improvement on level of 0.3% - 05% ( $k=1$ ) on condition that the sensor performance is on 0.1%( $k=1$ ) level.**

**This would be 25% - 40% from the Perfect Observatory ( $U = 1.25 - 1.4$ )**

**(!) Residue error 0.1%( $k=1$ ) is realistic only for well behaving sensor.**

### **3) CLARREO Reference Inter-Calibration: Future Work**

- 1) Baseline CLARREO RS RI activities at NASA LaRC (direct funding):**
  - Empirical and theoretical modeling of polarization at TOA for RI (C. Lukashin, W. Sun).
  - Demonstration of RI algorithms in RS using SCIAMACHY, CERES, PARASOL, MODIS and VIIRS data. (C. Lukashin, D. Doelling, Z. Jin, J.C. Currey, W. Sun, X. Xiong, J. Butler, P. Speth, C. Roithmayr, et al.), depends on CLARREO funding.
- 2) ROSES 2011 proposals (to be submitted):**
  - A37 (ACCESS): J.C. Currey et al., “Multi-Instrument Inter-Calibration Framework”.
  - A29 (Intercal): C. Lukashin, W. Sun, and X. Xiong, “Development of Polarization Models to Account for Spaceborne Imager Sensitivity to Polarization on Orbit”.
- 3) Publication of completed work:**
  - C. Lukashin, Z. Jin, W. Sun, K. Thome, B.A. Wielicki, D.F. Young: “Uncertainty Estimates for Imager Reference Inter-calibration with CLARREO Reflected Solar Spectrometer” (presented material).
  - C. Lukashin, Z. Jin, D.G. Macdonnell, K. Thome, B.A. Wielicki, D.F. Young: “Restriction on Instrument Sensitivity to Polarization for Climate Observing System in Reflected Solar” (requirement for CLARREO RS instrument).
  - W. Sun, C. Lukashin, et al.: “Modeling Polarization at TOA for Inter-calibration of Spaceborne Sensors” (theoretical and empirical polarization modeling).
  - C. Roithmayr, C. Lukashin, P. Speth, B.A. Wielicki, D.F. Young: “Reference Inter-Calibration Ability of CLARREO Reflected Solar Spectrometer” (RS RI sampling).

## **4) SCIAMACHY Level-1 Spectral Radiance Data (SCIAMACHY/ENVISAT nadir observations)**

- ◆ **POC at NASA LaRC: Constantine Lukashin**
- ◆ **Data version: 7.01 (optics degradation: M-factors v. 7.03)**
- ◆ **Time period: 2002.08 – Present**
- ◆ **Data format at LaRC: binary (made on little-endian system)**
- ◆ **Expected data set volume: about 4 Tb**
- ◆ **Estimated readiness: end of Summer 2011**
- ◆ **Example of reader code + set of functions available:**
  - in C++ from C. Lukashin (optional ROOT applications)
  - in FORTRAN-90 from Z. Jin
  - MODIS-based scene description (separate files)
- ◆ **Access from outside NASA LaRC (D. Young / C. Currey):**
  - Preferred method: NASA VPN account + access to CLARREO SCF
  - Registration at ESA for SCI\_NL\_1P data product is REQUIRED
  - Registered users: C. Lukashin, LASP, Z. Jin, D. Doelling, X. Liu.